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(54) **SLOT LINE BAND REJECT FILTER**

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(52) **U.S. Cl.** **333/204**; 333/205; 333/219
(58) **Field of Search** 333/204, 205, 333/219

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(57) **ABSTRACT**

A slot line band reject pass filter including a substrate of insulating material having slot line primary conductors formed thereon. One or more supplemental conductors are preferably coupled to the slot line primary conductors to achieve rejection of a desired frequency. Several embodiments of supplemental conductors are disclosed including substantially closed loop and non loop segments that extend in a range from parallel to perpendicular from the primary conductors. The supplemental conductors may be directly or electromagnetically coupled, or both.

22 Claims, 2 Drawing Sheets

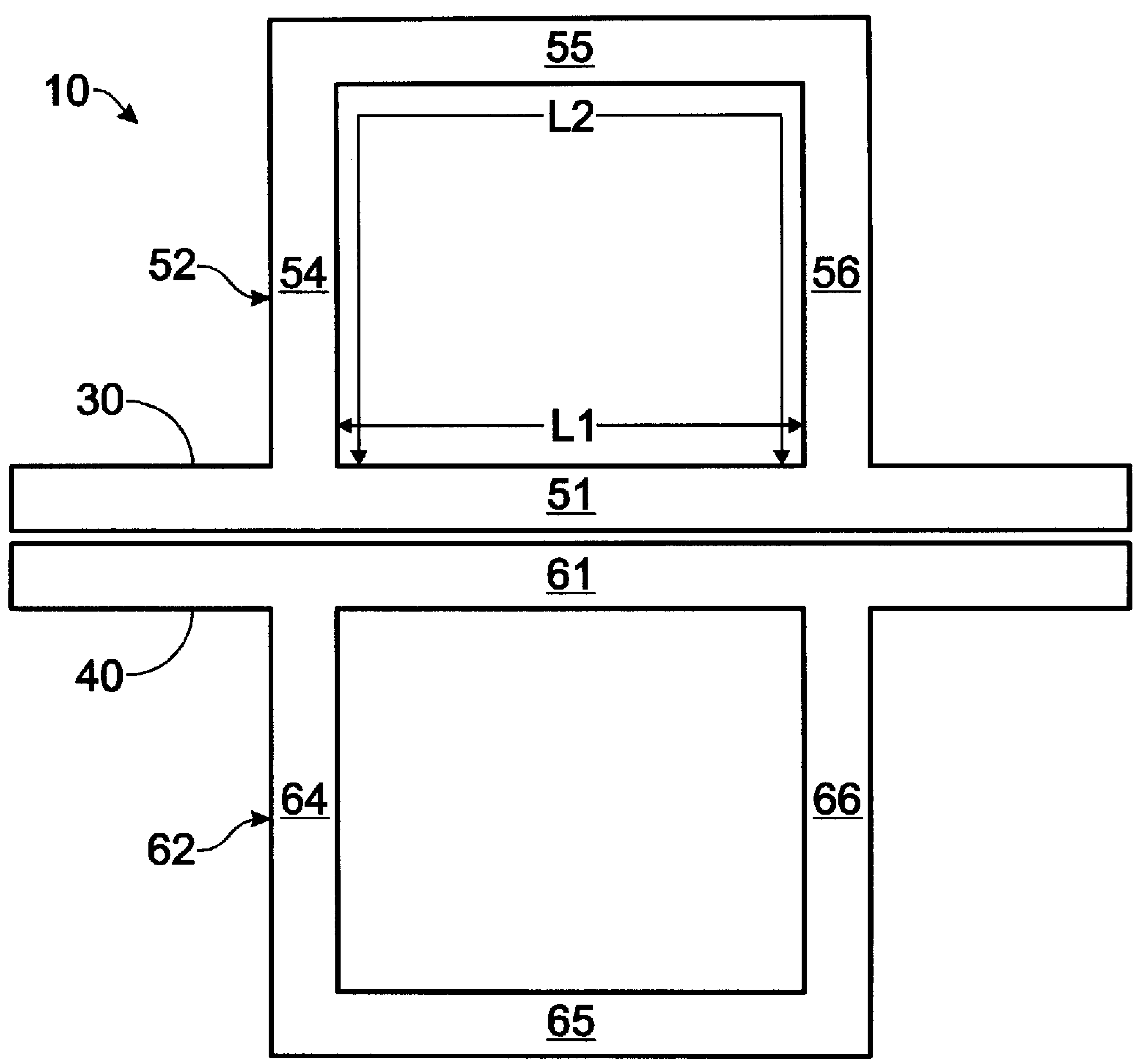


Fig. 1

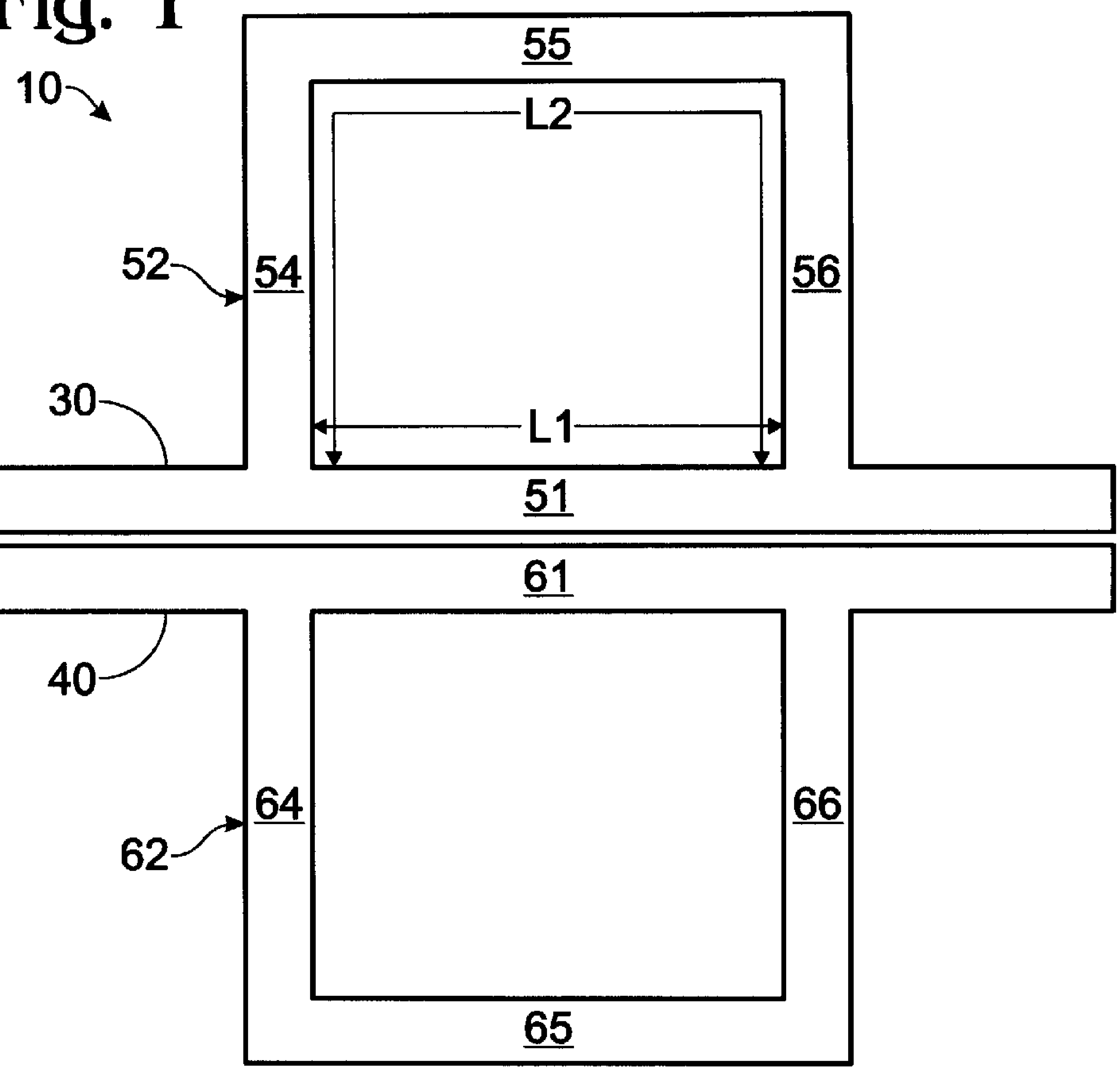


Fig. 2A

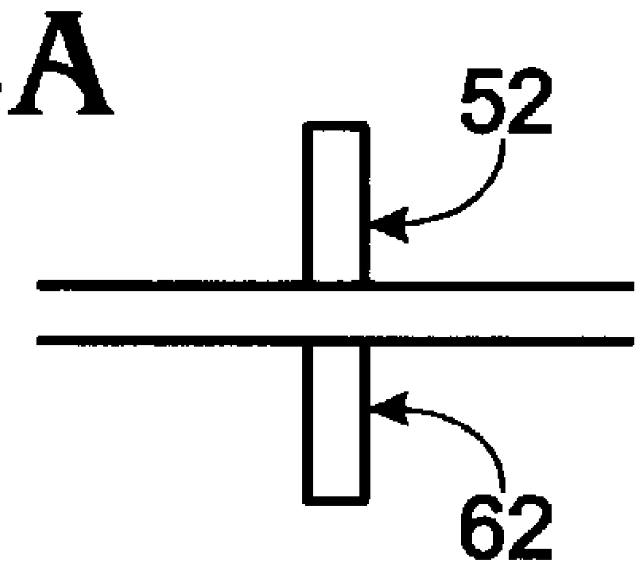


Fig. 2B

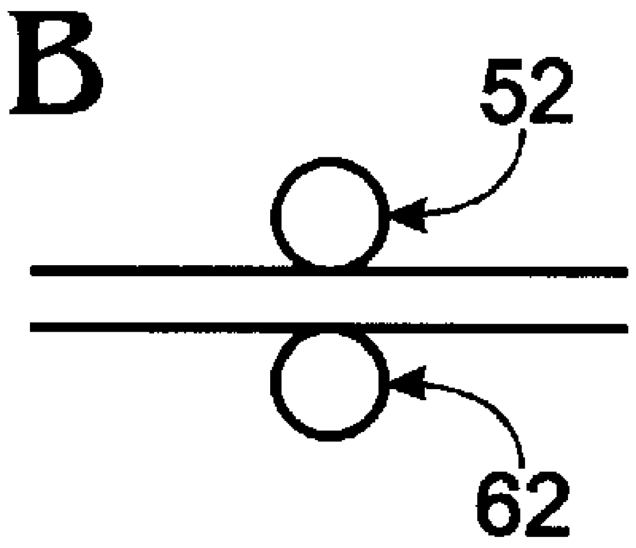


Fig. 2C

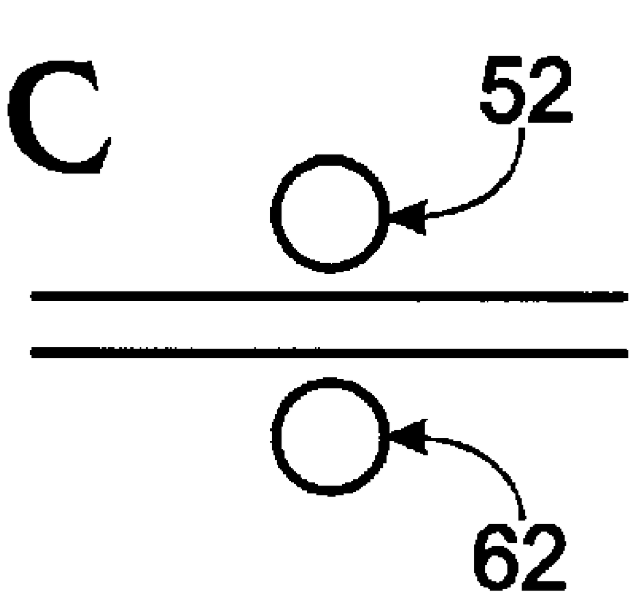


Fig. 5

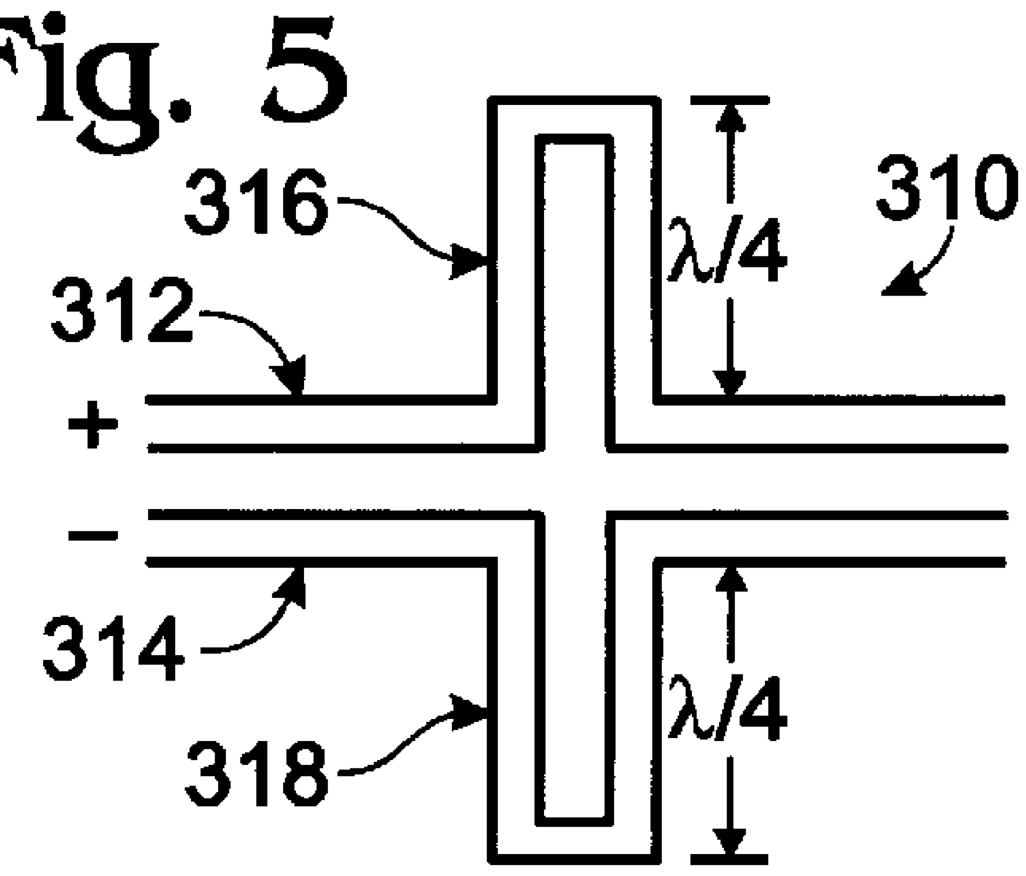


Fig. 6

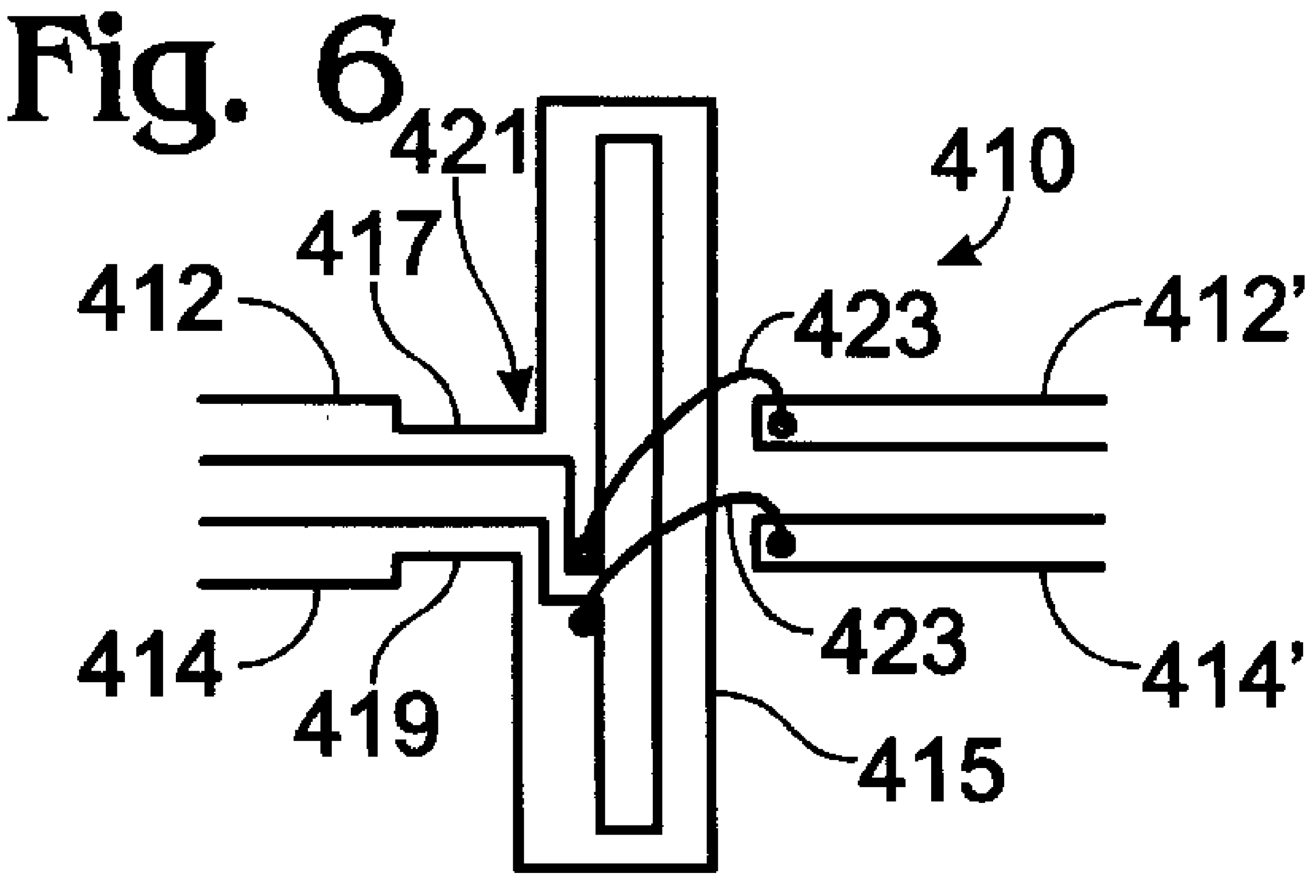


Fig. 4

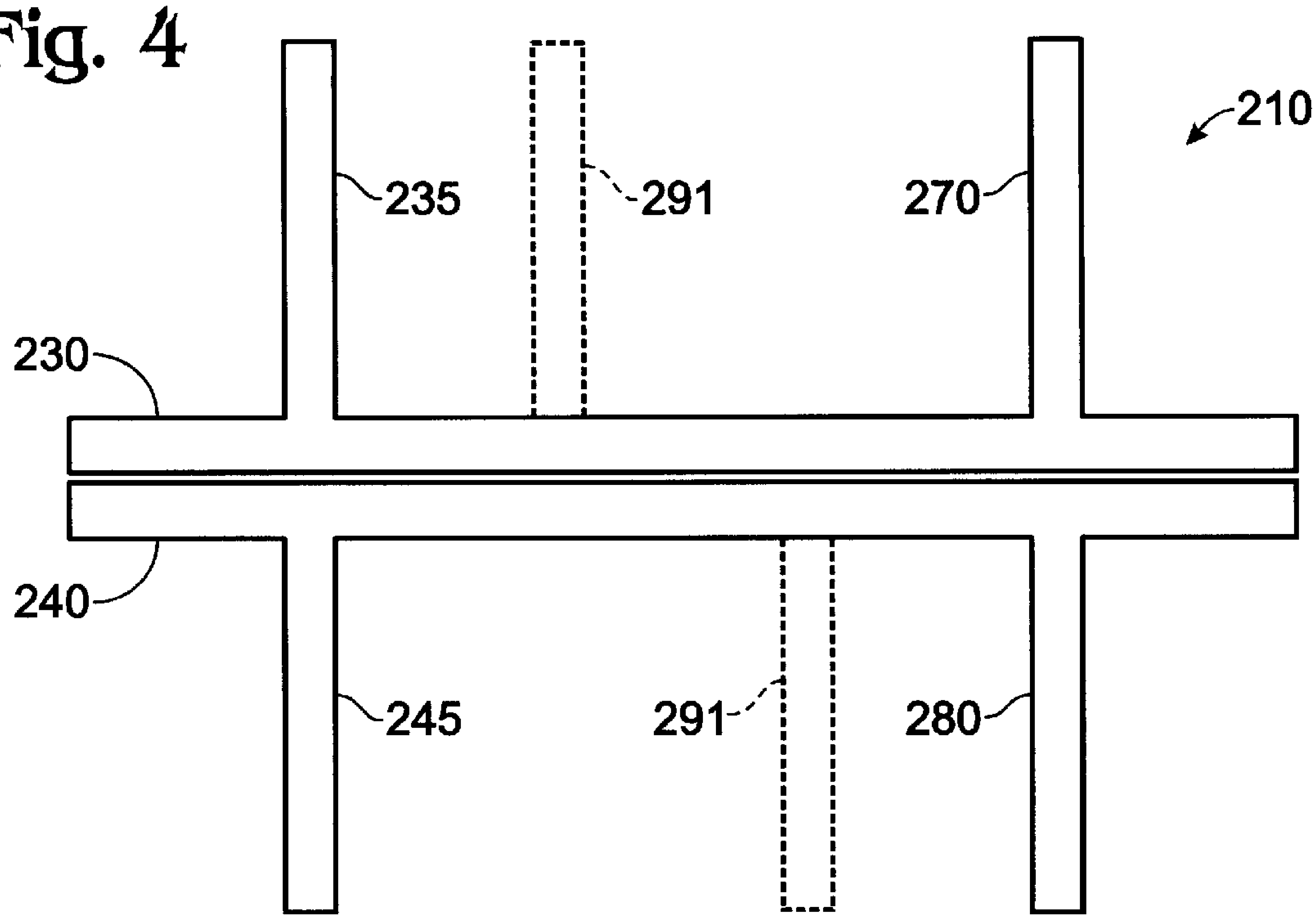


Fig. 3A

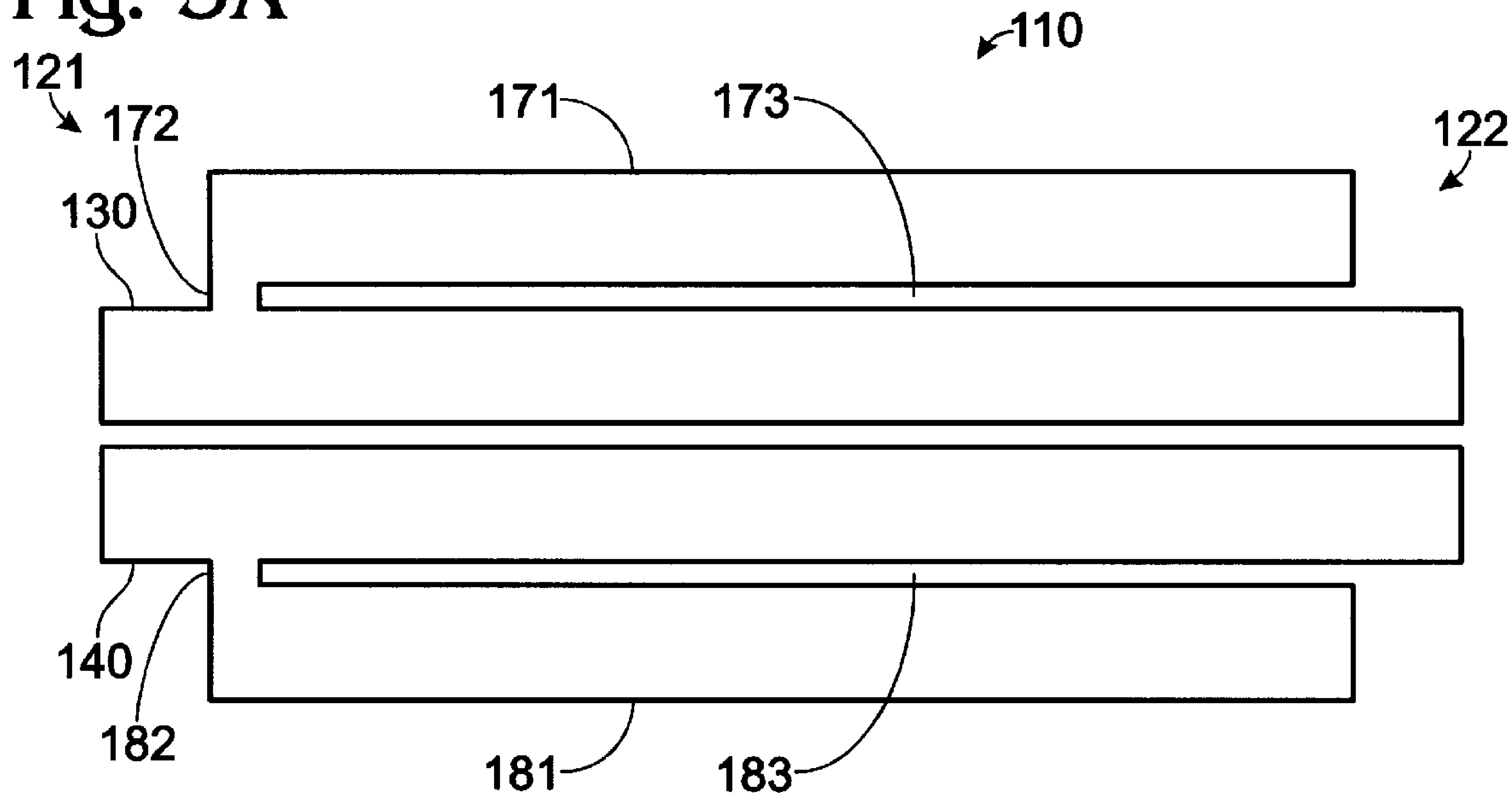
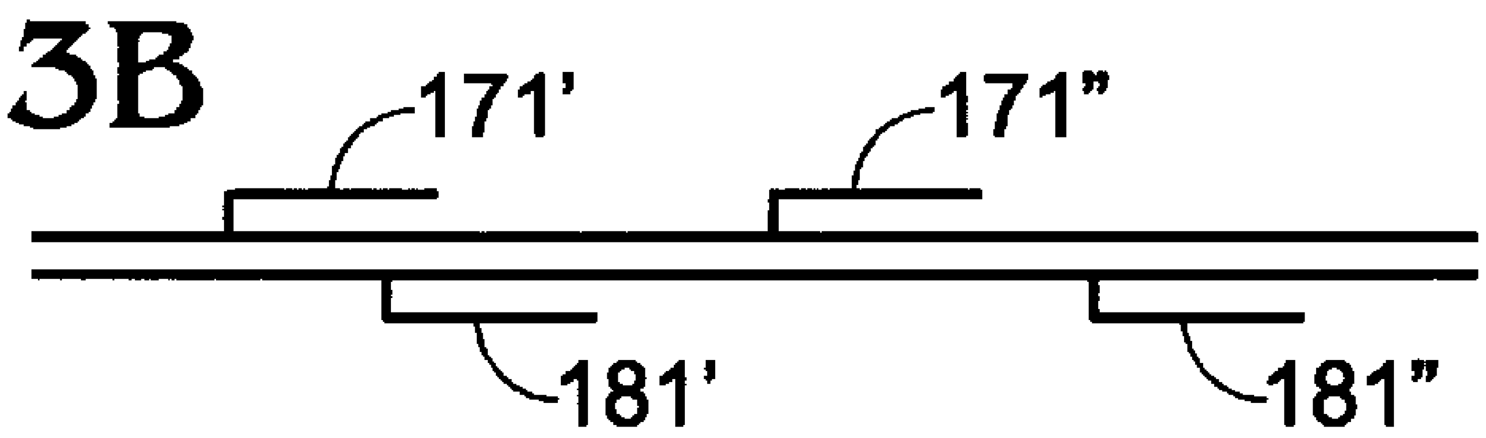


Fig. 3B



SLOT LINE BAND REJECT FILTER

FIELD OF THE INVENTION

The present invention relates to slot line band reject filters.

BACKGROUND OF THE INVENTION

The prior art provides several types of filters for use with radio frequency signals including high pass, low pass, band pass, notch and other types of filters fabricated in lumped or distributed form. Filters of these types have been formed in a variety of transmission media.

To accommodate higher frequency signals some filters have been fabricated in microstrip transmission media using distributed elements. Microstrip transmission media generally consists of one or more thin conducting strips of finite width that are arranged parallel with a single extended conducting ground plan. In its common form, the strips are fixed to one side of an insulating substrate and the ground plane is attached to the other side. While microstrip transmission media have been recognized as possible conductors for higher frequency signals, microstrip transmission media also have disadvantageous aspects. These aspects include that the fabrication of microstrip circuits is process intensive, involving (1) metalization on two sides of a substrate and (2) the formation of interconnecting vias between the two surface materialization layers to achieve proper grounding.

Coplanar waveguide (CPW) and slot line are alternative types of transmission media. Both CPW and slot line support uniplanar fabrication, though they have not been used widely for high frequency signal propagation.

To provide less expensive and more efficient circuit construction, a need exists to form circuits that support high frequency operation (approximately >1 GHz) in a uniplanar transmission media. To provide necessary signal processing, a need exists to provide circuit components such as band reject filters and the like in such media. Suitable band reject filters will provide LO, image reject and spurious frequency filtering.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a slot line band reject filter.

It is another object of the present invention to provide a slot line band reject filter that affords flexibility in the design of performance characteristics.

It is another object of the present invention to provide a band reject filter that is compact in size.

It is also an object of the present invention to provide a uniplanar implemented image reject filter that is suitable for use in a radio system.

These and related objects of the present invention are achieved by use of a slot line band reject filter as disclosed herein.

The attainment of the foregoing and related advantages and features of the invention should be more readily apparent to those skilled in the art, after review of the following more detailed description of the invention taken together with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of a slot line band reject filter in accordance with the present invention.

FIGS. **2**A–**2**C are diagrams of alternative embodiments of the slot line band reject filter of FIG. **1** in accordance with the present invention.

FIGS. **3**A–**3**B are diagrams of other embodiments of a slot line band reject filter in accordance with the present invention.

FIG. **4** is a diagram of other embodiments of a slot line band reject filter in accordance with the present invention.

FIG. **5** is a diagram of another embodiment of a band reject slot line filter in accordance with the present invention.

FIG. **6** is a diagram of another embodiment of a band reject slot line filter in accordance with the present invention.

DETAILED DESCRIPTION

Slot line transmission media generally consists of two semi-infinite coplanar conducting planes affixed to the same side of an insulating substrate of arbitrary thickness and separated by a finite gap. In the present invention, the slot line transmission media is preferably implemented in strip format. Amongst other benefits, slot line transmission media provides significant flexibility in component layout and the benefits of uniplanar fabrication.

The filters described herein are preferably formed on a substrate that may include fused silica, ceramic, plastic, Teflon, glass, air or the like. Though preferably formed with slot line strips, filters of the present invention may also be formed with infinite or semi-infinite ground planes.

Referring to FIG. **1**, a diagram of a band reject filter in accordance to the present invention is shown. The band reject filter **10** includes a positive signal line **30** and a negative signal line **40**. Positive signal line **30** is comprised of a principal positive conductor **51** and three conducting segments **54–56** (which form a supplemental conductor) arranged to form a loop **52** in conjunction with a section of conductor **51**. Similarly, negative signal line **40** is comprised of a principal negative conductor **61** and three conducting segments **64–66** (which form a supplemental conductor) arranged to form a loop **62** in conjunction with a section of conductor **61**.

Segments **54–56** have a combined length termed L**2**, while the section of conductor **51** defined by the intersection of segments **54**,**56** has a length termed L**1**. A similar conductor arrangement is provided in negative signal line **40**. The rejection center frequency of filter **10** is inversely proportional to the difference between L**1** and L**2**. Rejection of a desired frequency is achieved through destructive interference.

It should also be recognized that although members **54–56** are straight and orthogonally arranged, these members (and the principal conductors to which they attach) can be curved, zigzag, trapezoidal, circular, amorphous or otherwise shaped.

With respect to design criteria, it has been recognized that the center frequency, fc, of filter **10** relates to L**1** and L**2** as follows:

$$fc \cong \frac{C}{2(\epsilon_r)^{1/2}((L1 - L2)/2.91)}$$

where C is the speed of light, L**1** and L**2** are as shown in FIG. **1**, and ϵ_r is the dielectric constant of the substrate. It should be recognized that fc is proportional to 1/(L**1**–L**2**) because fc generally increases as L**2** increases.

Referring to FIGS. **2A–2C**, diagrams of alternative embodiments of the band reject filter of FIG. **1** in accordance with the present invention are shown. FIG. **2A** illustrate a filter in which the loops **52,62** are configured such that the long dimension of L2 is disposed substantially perpendicular to the center line of the filter.

FIG. **2B** illustrates the formation of loops **52,62** in a circular, oval or elliptical pattern. In this filter, L2 may approach a maximum while L1 may approach a minimum, depending on the final design. FIG. **2C** illustrates generally circular loops **52,62** that are electromagnetically coupled to primary conductors **51,61**. Though loops **52,62** of FIGS. 2B–2C are substantially circular as illustrated, other shapes may be utilized.

Referring to FIG. **3A**, a diagram of another embodiment of a band reject filter **110** in accordance with the present invention is shown. Band reject filter **110** includes positive and negative signal lines **130,140**, respectively. Supplemental conductors (or resonators) **171,181** are respectively coupled through connecting conductors **172,182** and through gaps **173,183** to the positive and negative signal lines **130,140**. The supplemental conductors **171,181** each have a length of approximately one-quarter wavelength of the rejection center frequency. Though conductors **172,182** are shown connecting the supplemental conductors to signal lines **130,140** proximate an input **121** of filter **110**, one or both of connecting conductors **172,182** could alternatively be provided proximate an output **122** of filter **110** (i.e., connected at the other end of the supplemental conductor from the end shown). Frequency cancellation occurs by presenting a short circuit at the rejection center frequency to both the positive and negative signal lines **130,140**. The short circuit is due to the open circuit at the end of supplemental conductors **171,181** transformed through a quarter-wave.

The impedance of the transmission line can be varied to optimize filter characteristics by modifying the width of supplemental conductors **171,181** and their respective spacing from the positive and negative signal lines.

Referring to FIG. **3B**, a diagram of another embodiment of a slot line band reject filter in accordance with the present invention is shown. The filter arrangement shown in FIG. **3B** is similar to that shown in FIG. **3A**, however, the supplemental conductors **171,181** are staggered as compared to being generally symmetrically positioned as shown in FIG. **3A**. The left most pair of supplemental conductors **171',181'** overlapped, while the right most pair of supplemental conductors **171',181'** do not overlap. While the conductors **171,181** are shown paired, it should be recognized that the present invention includes non-pair supplemental conductors.

Referring to FIG. **4**, a diagram of another embodiment of a slot line band reject filter **210** in accordance with the present invention is shown. Filter **210** comprises positive and negative principal conductors **230,240**, respectively. A pair of resonators (or supplemental conductors) **235,245**, are coupled to the positive and negative signal lines. Each of these resonators is preferably a quarter wavelength (or multiple thereof) of a center frequency (of the rejection frequency) in length and open circuited such that each presents a short circuit at the principal conductor to signals approximately at the rejection center frequency. The short circuit attenuates these signals.

A second pair of resonators **270,280** may also be coupled to positive and negative signal lines **230,240**. These resonators **270,280** are preferably a quarter wavelength of a center frequency in length and their spacing from resonator

235,245 is preferably approximately a half wavelength of the center frequency. The spacing is also preferably optimized to achieve a required rejection profile (band rejection depth and width).

It should be recognized that the band reject filter of FIG. **4** can be constructed by using only a single resonator, such as resonators **235** or **245**, a plurality of staggered single resonators, a single pair of resonators or a plurality of pairs of resonators, or a combination thereof. Furthermore, supplemental conductors (resonators) of the types shown in FIGS. **3** and **4** could be combined. Considerations in filter design include providing a sufficient number and arrangement of resonators to achieve a desired rejection profile, while minimizing circuit size. Two single, staggered (asymmetrically arranged) resonators **291,292** are shown in dashed lines to achieve a desired band rejection filter profile.

It should further be recognized that while rectilinear edged supplemental conductors are shown herein, these conductors may have a non-rectilinear shape, including amorphous shapes that are empirically or otherwise determined to provide a desired profile. In addition, the performance of the filters described herein may be modified (optimized) by modifying the width of the supplemental conductors that achieve signal rejection.

Referring to FIG. **5**, a diagram of another embodiment of a slot line band reject filter **310** in accordance with the present invention is shown. Filter **310** includes positive and negative supplemental conductors **316** and **318** that respectively extend from and return to the positive and negative principal conductors **312** and **314** in such a manner as to form transmission line (slot line) segments. The length of these transmission line segments **316,318** is preferably one-quarter wavelength of the rejection frequency such that a voltage minima is returned to the principal conductors for that frequency.

Referring to FIG. **6**, a diagram of another embodiment of a slot line band reject filter **410** in accordance with the present invention is shown. Filter **410** includes a supplemental conductor **415** which is connected to the positive and negative principal conductors **412,414** and forms a loop that is approximately an integer multiple of a wavelength of the rejection frequency. Inductive traces **417,418** and interdigitated capacitor **421** provide impedance matching. Leads **423** provide propagation of non-rejected frequencies through to output positive and negative single conductors **412',414'**.

While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification, and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth, and as fall within the scope of the invention and the limits of the appended claims.

What is claimed is:

1. A slot line band reject filter, comprising:

a substrate of electrically insulating material having a first surface;

a first conductor formed in strip format on said first surface of said substrate;

a second conductor formed in strip format on said first surface of said substrate and arranged with said first conductor so as to form a slot line transmission media; and

a first supplemental conductor formed in strip format on said first surface of said substrate and coupled to at least one of said first and second conductors in such a way as to bring about a substantial rejection of a desired frequency.

2. The slot line band reject filter of claim **1**, further comprising a second supplemental conductor formed on said first surface of said substrate and coupled to the other of said first and second conductors in such a way as to bring about a substantial rejection of a desired frequency.

3. The slot line band reject filter of claim **1**, wherein said first supplemental conductor has a length of approximately an odd integer multiple of a quarter wavelength of said desired frequency.

4. The slot line band reject filter of claim **1**, wherein said first supplemental conductor forms a first loop.

5. The slot line band reject filter of claim **4**, wherein said first loop has a long dimension disposed generally perpendicular to said at least one of said first and second conductors.

6. The slot line band reject filter of claim **4**, wherein said first loop is electromagnetically coupled to said at least one of said first and second conductors.

7. The slot line band reject filter of claim **1**, wherein said first supplemental conductor is electromagnetically coupled to said at least one of said first and second conductors.

8. The slot line band reject filter of claim **2**, wherein said first and second supplemental conductors are arranged in a substantially parallel relationship with the conductors to which they are coupled.

9. The slot line band reject filter of claim **2**, wherein said first and second supplemental conductors are arranged asymmetrically about a centerline of the first and second conductors.

10. The slot line band reject filter of claim **1**, wherein said first supplemental conductor forms a transmission line segment.

11. The slot line band reject filter of claim **10**, wherein said transmission line segment has a length of approximately an odd integer multiple of one-quarter wavelength of the rejection frequency.

12. The slot line band reject filter of claim **1**, wherein said first supplemental conductor is connected between said first conductor and said second conductor and forms a resonator loop having a length of approximately an integer multiple of a wavelength of the rejection frequency.

13. The slot line band reject filter of claim **12**, further comprising means for impedance matching formed within at least one of said first and second conductors and said loop.

14. A slot line band reject filter, comprising:

a substrate of electrically insulating material;

a first conductor formed in strip format on said substrate;

a second conductor formed in strip format on said substrate and arranged with said first conductor so as to form a slot line transmission media; and

supplemental conductive material coupled to at least one of said first and second conductors that achieves rejection of a desired frequency;

wherein said supplemental conductive material and said first and second conductors are all formed on the same side of said substrate.

15. The slot line band reject filter of claim **14**, wherein said supplemental conductive material forms a loop coupled to one of said first and said second conductors.

16. The slot line band reject filter of claim **14**, wherein said supplemental conductive material forms a loop connected between said first and said second conductors.

17. The slot line band reject filter of claim **14**, wherein said supplemental conductive material forms a transmission line segment.

18. A slot line band reject filter, comprising:

a substrate of electrically insulating material;

a first conductor formed in strip format on said substrate;

a second conductor formed in strip format on said substrate and arranged with said first conductor so as to form a slot line transmission media; and

first supplemental conductive material coupled to at least one of said first and second conductors that has a length of an integer multiple of one-quarter wavelength of a rejection frequency of said filter;

wherein said supplemental conductive material is formed on the same side of said substrate as said first and second conductors.

19. The slot line band reject filter of claim **18**, further comprising second supplemental conductive material coupled to the other of said first and second conductors that has a length of approximately an odd integer multiple of one-quarter wavelength of the rejection frequency.

20. The slot line band reject filter of claim **18**, wherein said first supplemental conductive material forms a transmission line segment.

21. A slot line band reject filter, comprising:

a substrate of electrically insulating material;

a first conductor formed in strip format on said substrate;

a second conductor formed in strip format on said substrate and arranged with said first conductor so as to form a slot line transmission media; and

a first supplemental conductor formed in strip format and coupled to at least one of said first and second conductors in such a way as to bring about a substantial rejection of a desired frequency;

a second supplemental conductor coupled to the other of said first and second conductors in such a way as to bring about a substantial rejection of a desired frequency; and

wherein said first and second supplemental conductors are arranged in a substantially parallel relationship with the conductors to which they are coupled.

22. A slot line band reject filter, comprising:

a substrate of electrically insulating material;

a first conductor formed in strip format on said substrate;

a second conductor formed in strip format on said substrate and arranged with said first conductor so as to form a slot line transmission media; and

a first supplemental conductor formed in strip format and coupled to at least one of said first and second conductors in such a way as to bring about a substantial rejection of a desired frequency; and

a second supplemental conductor coupled to the other of said first and second conductors in such a way as to bring about a substantial rejection of a desired frequency;

wherein said first and second supplemental conductors are arranged asymmetrically about a centerline of the first and second conductors.

* * * * *